

SEMICONDUCTOR DEVICE INCLUDING DUTY CYCLE CORRECTION CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a synchronous semiconductor memory device, and more particularly, the present invention relates to a synchronous semiconductor memory device including a duty cycle correction (DCC) circuit for correcting the duty cycle of a clock.

[0002] A claim of priority is made to Korean Patent Application No. 2003-3295, filed on 17 January 2003, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein in its entirety by reference.

2. Description of the Related Art

[0003] In a synchronous semiconductor memory device that receives/outputs data in phase with an internal clock, the duty cycle of the internal clock is a factor that affects operational characteristics of the device. The duty cycle of a clock is defined as the ratio of the pulse width to the pulse duration of the clock.

[0004] In general, most digital clock applications, such as those used in the field of semiconductor integrated circuits, rely on clock duty cycles of 50 %. A clock with a duty cycle of 50 % is a clock in which high-level and low-level durations of each pulse of the clock are the same.

[0005] It is often necessary to precisely control the duty cycle of a clock. For example, in the case of a synchronous semiconductor memory device that outputs data in phase with a clock, the output data may be distorted if the clock duty cycle is not precisely adjusted to 50 %. Accordingly, a duty cycle correction (DCC) circuit is used when necessary to adjust an input clock having duty cycle that is above or below 50 % to obtain a clock signal having a duty cycle of 50 %.

[0006] In the meantime, double data rate (DDR) synchronous semiconductor memory devices have been developed in an effort to increase operating speeds. The DDR allows data to be input or output at both rising and falling edges of a clock.

Accordingly, precise adjustment of the clock duty cycle is especially important in the case of DDR synchronous semiconductor memory devices.

[0007] FIG. 1 illustrates a conventional scheme of correcting the duty cycle of an input clock signal *CLK_IN*. As shown in FIG. 1, the input clock signal *CLK_IN* is input to a DCC circuit 12 via an amplifier 11. The DCC circuit 12 corrects the duty cycle of the input clock signal *CLK_IN* and outputs an output signal *CLK_OUT* as the result of the correction.

[0008] Here, the amplifier 11 amplifies the voltage levels of the input *CLK_IN* to obtain an amplitude swing between a ground voltage *VSS* and a power supply voltage *VDD*.

[0009] FIG. 2 is a circuit diagram of the DCC circuit 12 of FIG. 1. Referring to FIG. 2, the DCC circuit 12 includes first through third inverters 210, 220, and 230. The first inverter 210 includes a PMOS transistor *MP21* and an NMOS transistor *MN22*, and the second inverter 220 includes a PMOS transistor *MP23* and an NMOS transistor *MN24*.

[0010] The first inverter 210 receives and inverts an input first clock signal *CLK_A*, and outputs the inverted result to a node *N*. The second inverter 220 receives and inverts an input second clock signal *CLK_B*, which is opposite in phase to the first clock signal *CLK_A*, and outputs the inverted result to the same node *N*. That is, the output terminal of the first inverter 210 and the output terminal of the second inverter 220 are both connected to the node *N*. The third inverter 230 inverts a signal received from the node *N* and outputs the inverted result as an output signal *CLK_OUT*. The output signal *CLK_OUT* is a clock signal having a corrected duty cycle.

[0011] However, process variations in the fabrication of semiconductor memory device may cause distortion in the duty cycle of the output clock signal. As previously mentioned, the signal *CLK_IN* output from the amplifier 11 is input directly to the DCC circuit 12 and the DCC circuit 12 corrects the duty cycle of the clock and outputs an output signal *CLK_OUT* as the result of the correction. Process variations can alter the slope of the signal *CLK_IN* output from the amplifier 11, and as a result, the signal *CLK_IN* output from the DCC circuit 12 can be distorted.

[0012] If the distortion of the duty cycle of a clock is beyond design margins that the system can handle, a fatal error may occur during the operation of the system.

SUMMARY OF THE INVENTION

[0013] According to an aspect of the present invention, there is provided a semiconductor device which includes a duty cycle correction (DCC) circuit that receives first and second clock signals and outputs a duty cycle adjusted clock signal, and a control circuit that detects a process variation and controls respective
10 slew rates of the first and second clock signals based on the detected process variation.

[0014] It is preferable that the DCC circuit includes a first inverter having an input that receives the first clock signal, a second inverter having an input that receives the second clock signal, a third inverter having an input commonly
15 connected to outputs of the first and second inverters, a first variable capacitor connected between the input of the first inverter and a ground voltage, and a second variable capacitor connected between the input of the first inverter and the ground voltage. In this case, the respective capacitance values of the first and second variable capacitors are set by the control circuit.

[0015] It is preferable that the control circuit includes a process variation detector that detects the process variation and outputs a voltage signal corresponding to the process variation, a differential amplifier that receives the signal output from the process variation detector and a reference signal, and amplifies a difference between the voltage signal and the reference signal, and an
20 analog-to-digital converter (ADC) that converts a signal output from the differential amplifier into a digital signal. In the case, the digital signal output from the ADC is a control signal for controlling the capacitance values of the first and second capacitors.

[0016] The process variation detector preferably includes a plurality of series
25 connected PMOS transistors that have gates connected to a ground voltage, and a plurality of series connected NMOS transistors that have gates connected to a reference supply voltage.

[0017] The phase of the first clock signal is preferably opposite to a phase of the second clock signal, and the device may further include an amplifying circuit that receives an external clock signal and outputs the first and second clock signals corresponding to the external clock.

5 **[0018]** The duty cycle adjusted clock signal is an internal clock signal of a synchronous semiconductor memory device, such as a double data rate (DDR) synchronous semiconductor memory device.

[0019] According to another aspect of the present invention, there is provided a semiconductor device which includes a first inverter having an input that receives a first clock signal, a second inverter having an input that receives a second clock signal which is opposite in phase to the first clock signal, a third inverter having an input commonly connected to outputs of the first and second inverters, a first capacitor unit having a plurality of capacitors that are selectively connected between the input of the first inverter and a ground voltage to define a first capacitance value
10 between the first inverter and the ground voltage, a second capacitor unit having a plurality of capacitors that are selectively connected between the input of the second inverter and the ground voltage to define a second capacitance value between the second inverter and the ground voltage, and a control circuit that detects a process variation and controls respective slew rates of the first and second clock signals
15 based on the detected process variation. The control circuit controls the respective slew rates of the first and second clock signals by adjusting the first and second capacitance values of the first and second capacitor units, respectively.
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BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The above and other aspects and advantages of the present invention will become more apparent from the detailed description that follows, with reference to the accompanying drawings, in which:

5 [0021] FIG. 1 illustrates a conventional scheme of correcting the duty cycle of an input clock;

[0022] FIG. 2 is a circuit diagram of a duty cycle correction (DCC) circuit of FIG. 1;

10 [0023] FIG. 3 is a block diagram of a semiconductor device that includes a circuit for correcting the duty cycle of a clock according to a preferred embodiment of the present invention;

[0024] FIG. 4 is a circuit diagram of a DCC circuit of FIG. 3; and

[0025] FIG. 5 is a circuit diagram of a control circuit according to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0026] Hereinafter, preferred embodiments of the present invention will be described in detail with reference to the accompanying drawings. The same reference numerals represent the same elements throughout the drawings.

20 [0027] FIG. 3 is a block diagram of a semiconductor device 300 that includes a circuit for correcting the duty cycle of a clock while compensating for process variations, according to a preferred embodiment of the present invention. For example, the device 300 may be contained in a synchronous semiconductor memory, such as a double data rate (DDR) synchronous semiconductor memory. Referring to FIG. 3, the semiconductor device 300 includes an amplifier 31, a duty cycle correction (DCC) circuit 32, and a control circuit 33.

[0028] The amplifier 31 receives an input clock signal *CLK_IN*, changes a voltage level of the input clock signal *CLK_IN* such that the signal has an amplitude swing between a ground voltage *VSS* and a power supply voltage *VDD*.

30 [0029] The DCC circuit 32 receives the amplified signal from the amplifier 31, corrects a duty cycle of the signal, and outputs an output signal *CLK_OUT* as the result of the correction.

[0030] The control circuit 33 includes a process variation detector 35, a differential amplifier 37 and an analog-to-digital converter (ADC) 39, and outputs a control signal *CTRL* which controls the slew rate of the clock signal output from the amplifier 31 based on a process variation exhibited by the semiconductor device 300.

[0031] The process variation detector 35 detects the process variation in the semiconductor device 300 and outputs the result of the detection. The differential amplifier 37 compares a signal output from the process variation detector 35 and a predetermined reference voltage *VREF*, amplifies a difference between the signal and the predetermined reference voltage *VREF*, and outputs the result of amplification. The ADC 39 receives a signal output from the differential amplifier 37 and outputs a digital signal corresponding to the received signal. The digital signal output from the ADC 39 is the control signal *CTRL*. The control signal *CTRL* is input to the DCC circuit 32 and adjusts the slope, i.e., slew rate, of the amplified clock signal output from the amplifier 31.

[0032] Hereinafter, a process that is performed faster than a typical process will be defined as a fast process, and a process that is performed more slowly than the typical process will be defined as a slow process. Also by definition, a semiconductor device that is fabricated using the typical process will allow for the correction of the clock duty cycle without the need to compensate for a process variation. On the other hand, a semiconductor device that is fabricated using the fast process or the slow process requires compensation for a process variation in order to obtain a clock having a correct duty cycle.

[0033] More specifically, if the semiconductor device is fabricated using the fast process, the slope of the amplified clock signal output from the amplifier 31 must be slightly adjusted, whereas if the semiconductor device is fabricated using the slow process, the slope of the amplified clock signal output from the amplifier 31 must be largely adjusted.

[0034] In FIG. 3, the reference voltage *VREF* is a predetermined voltage signal indicative of the typical process. The difference between the signal output from the process variation detector 35 and the predetermined reference voltage *VREF* is representative of the degree of process variation in the semiconductor device 300. The duty cycle of the clock signal can be precisely corrected by

adjusting the slope of the amplified signal output from the amplifier 31 in accordance with the degree of process variation.

[0035] FIG. 4 is a circuit diagram of the DDC circuit 32 of FIG. 3. Referring to FIG. 4, the DCC circuit 32 includes first through fourth inverters 41, 42, 43, and 44, and first and second capacitor units 45 and 46. For convenience, connection of the control circuit 33 is also illustrated in FIG. 4.

[0036] The first inverter 41 receives and inverts a first clock signal *CLK_A* and outputs the inverted result. The second inverter 42 receives and inverts a second clock signal *CLK_B*, and outputs the inverted result. An output terminal of the first inverter 41 is connected to an output terminal of the second inverter 42. The third inverter 43 receives a signal output from the first inverter 41 and a signal output from the second inverter 42 and outputs an output clock signal *CLK_OUT* having a corrected duty cycle. The fourth inverter 44 inverts the output clock signal *CLK_OUT* output from the third inverter 43 and outputs an output clock signal *CLK_OUTB* also having a correct duty cycle.

[0037] The first capacitor unit 45 is connected between an input terminal of the first inverter 41 and a ground voltage *VSS*. The second capacitor unit 46 is connected between an input terminal of the second inverter 42 and the ground voltage *VSS*. A capacitance of the first capacitor unit 45 and a capacitance of the second capacitor unit 46 are variably set in response to the control signal *CTRL* output from the control circuit 33.

[0038] Each of the first and second capacitor units 45 and 46 of the DDC circuit 32 includes a plurality of capacitors. The capacitance of the first capacitor unit 45 is determined by selectively switching the capacitors of the first capacitor unit 45 on and off in response to the control signal *CTRL*. Likewise, the capacitance of the second capacitor unit 46 is determined by selectively switching the capacitors of the second capacitor unit 46 on and off in response to the control signal *CTRL*.

[0039] Assuming that the first capacitor unit 45 includes ten capacitors of 1 pF, only eight capacitors are switched on when the control signal *CTRL* is a first control signal, and only two capacitors are switched on when the control signal *CTRL* is a second control signal. In this case, the capacitance of the first capacitor unit 45 is 8 pF when the first control signal is input and is 2 pF when the second control signal is input. Whether the control signal *CTRL* is the first control signal or the second

control signal is determined by the differential amplifier 37 shown in FIG. 3. The capacitance of the second capacitor unit 46 is variably set in the same way.

[0040] In the fast process, the control signal *CTRL* controls the capacitors of the first and second capacitor units 45 and 46 so as to increase their capacitances. In this case, the slope (slew rate) of the amplified clock signal output from the amplifier 11 decreases. In the slow process, the control signal *CTRL* controls the capacitors of the first and second capacitor units 45 and 46 to reduce their capacitances, and the slope of the amplified clock signal output from the amplifier 11 increases.

[0041] By controlling the capacitances of the first and second capacitor units 45 and 46, it is possible to precisely correct the slew rate of the amplified input clock, and thus the duty cycle of the output clock, notwithstanding the presence of a process variation.

[0042] The capacitances of the first and second capacitor units 45 and 46 are set in response to the control signal *CTRL*, but the construction of the first and second capacitor units 45 and 46 is not limited to the aforementioned structure having plural capacitors.

[0043] FIG. 5 is a circuit diagram of a control circuit 500 according to a preferred embodiment of the present invention. Referring to FIG. 5, the control circuit 500 includes a process variation detector 510, a differential amplifier unit 530, and an ADC unit 540. Unlike the control circuit 33 of FIG. 3, two signals are output from the ADC unit 540 of the control circuit 500, and thus, the control circuit 500 can detect process variations of both an NMOS transistor and a PMOS transistor.

[0044] The process variation detector 510 includes an NMOS process variation detector 51, a PMOS process variation detector 52, and a plurality of MOS transistors *MP51*, *MP52*, *MN53*, and *MN54*. The NMOS process variation detector 51 has a gate connected to a power supply voltage *VDD* and includes a plurality of NMOS transistors *MN510*, *MN520*, and *MN530* that are connected in series. The PMOS process variation detector 52 has a gate connected to a ground voltage *VSS* and includes a plurality of PMOS transistors *MP540*, *MP550*, and *MP560* that are connected to one another in series.

[0045] Gates of the PMOS transistors *MP51* and *MP52* are connected to each other. A source of the PMOS transistor *MP51* is connected to the power supply

voltage VDD and a drain of the PMOS transistor $MP51$ is connected both to a drain of the NMOS transistor $MN53$ and the gate of the PMOS transistor $MP52$. A source of the PMOS transistor $MP52$ is connected to the power supply voltage VDD and a drain of the PMOS transistor $MP52$ is connected to a drain of the NMOS transistor $MN510$ of the NMOS process variation detector 51.

[0046] Gates of the NMOS transistors $MN53$ and $MN54$ are connected to each other and their sources are connected to the ground voltage VSS . A drain of the NMOS transistor $MN54$ is connected to a drain of the PMOS transistor $MP560$ of the PMOS process variation detector 52.

[0047] The NMOS process variation detector 51 is connected between the drain of the PMOS transistor $MP52$ and the ground voltage VSS . The PMOS process variation detector 52 is connected between the power supply voltage VDD and the drain of the NMOS transistor $MN54$.

[0048] A drain terminal of the PMOS transistor $MP52$ inputs a signal output from the NMOS process variation detector 51 to a first differential amplifier 531, and a drain terminal of the NMOS transistor $MN54$ inputs a signal output from the PMOS process variation detector 52 to a second differential amplifier 532.

[0049] The differential amplifier unit 530 includes the first and second differential amplifiers 531 and 532, and amplifies a difference between an NMOS process variation output at node $N1$ and a reference voltage $VREF$, and a difference between a PMOS process variation output at node $N2$ and the reference voltage $VREF$.

[0050] The ADC unit 540 includes a first ADC 541 and a second ADC 542. The ADC unit 540 receives signals output from the first and second differential amplifiers 531 and 532 and converts these signals into digital control signals.

[0051] The MOS transistors $MP51$, $MP52$, $MN53$, and $MN54$ of the process variation detector 510 form a current mirror that acts as a reference current source.

[0052] The detection of process variations in the NMOS process variation detector 51 and the PMOS process variation detector 52 will now be described.

[0053] The sizes of the MOS transistors depend on a process variation, and accordingly, the amount of currents flowing through the MOS transistors or their turn-on resistances also depend on the process variation.

[0054] Returning to FIG. 5, all of the MOS transistors *MN510*, *MN520*, *MN530*, *MP540*, *MP550*, and *MP560*, which constitute the NMOS process variation detector 51 and the PMOS process variation detector 52, are turned on. Thus, turn-on resistances of the NMOS process variation detector 51 and the PMOS process variation detector 52 will be dependent on a process variation, and the voltages of output terminals *N1* and *N2* will also be dependent on a process variation.

[0055] For instance, in the case of the fast process, a large current flows through the NMOS process variation detector 51 and the PMOS process variation detector 52 and turn-on resistances of their transistors are reduced, thus applying high voltages to the output terminals *N1* and *N2*. In contrast, during the slow process, low voltages are applied to the output terminals *N1* and *N2*.

[0056] After detecting the process variation, the differential amplifier unit 530 receives the result of detection, measures a difference between the result of detection and the reference voltage *VREF*, amplifies the difference, and outputs the result of amplification. The ADC unit 540 converts signals output from the differential amplifier unit 530 into digital signals and generates control signals for controlling the capacitances of the first and second capacitor units 45 and 46 shown in FIG. 4.

[0057] As described above, a semiconductor memory device according to the present invention is capable of precisely correcting the duty cycle of a clock regardless of a process variation by adjusting the slope of an amplified clock signal input to a DCC circuit.

[0058] While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.